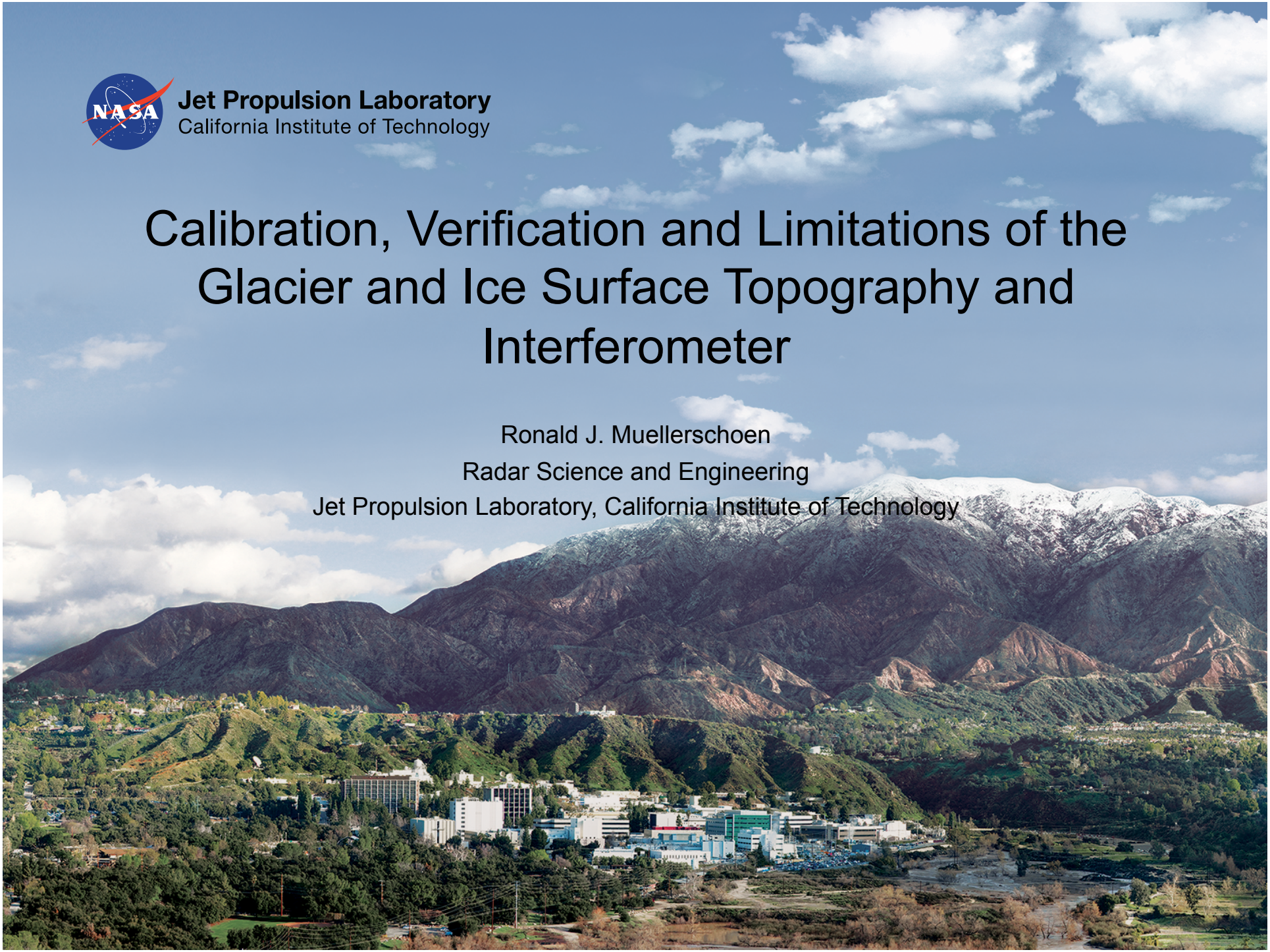


Jet Propulsion Laboratory
California Institute of Technology

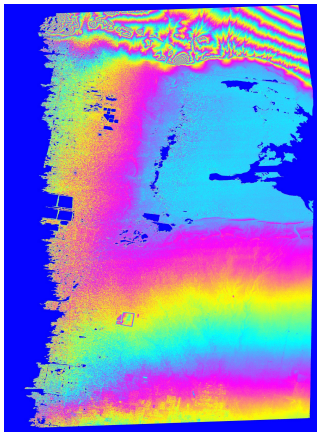
Calibration, Verification and Limitations of the Glacier and Ice Surface Topography and Interferometer

Ronald J. Muellerschoen
Radar Science and Engineering
Jet Propulsion Laboratory, California Institute of Technology

Glacier and Ice Surface Topography Interferometer

Ka-band single-pass InSAR (1/4 m) on a Gulf Stream III aircraft

Frequency	35.66 GHz
Bandwidth	80 MHz
Polarization	Horizontal
Transmit Power	> 80 Watts
Max Duty Cycle	10%
Look Angles	11-55 degrees
Swath	13 km

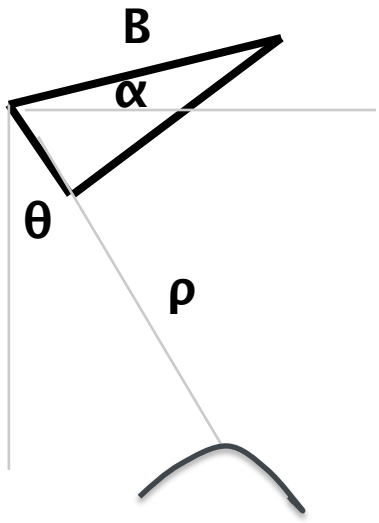


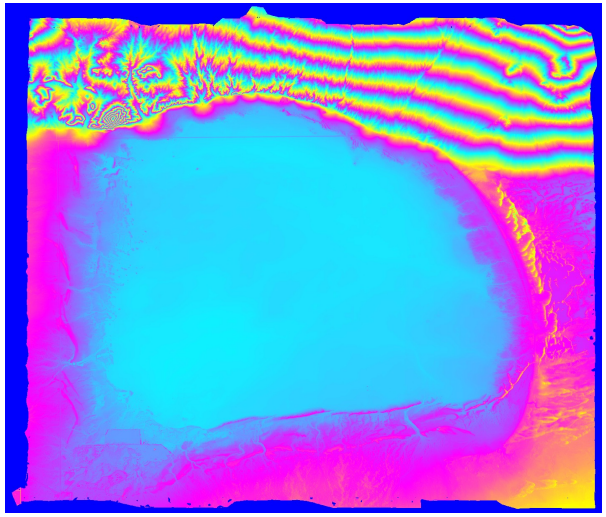
Calibration Method

Make use of existing Rosamond DEM and RCRA Trihedral 0.7 m CRs

- Use Ka-Band corner reflectors for range delay.
- Use DEM from Airborne Snow Observatory (ASO) survey of Rosamond Lake Bed January 2016 for Baseline, Roll, and Phase calibration.
- Compute phase screen from residual heights as function of IF phase.

$$AsoDEM - KaBandDEM = \frac{-\lambda\rho\sin(\theta)}{2\pi PB\cos(\theta-\alpha)}\delta\phi - \cos(\theta)\delta r - \rho\sin(\theta)\delta\alpha + \frac{\rho\sin(\theta)\tan(\theta-\alpha)}{B}\delta B$$





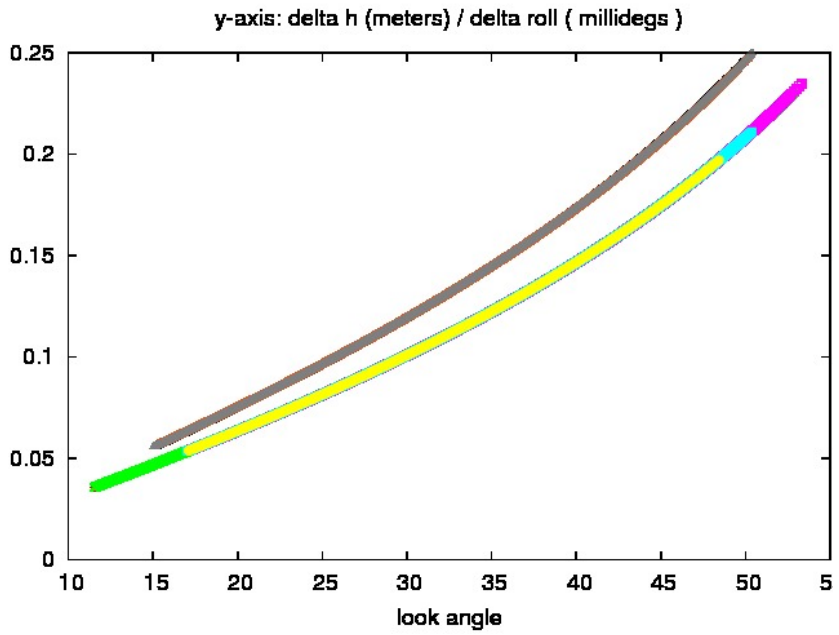
Calibration Key Sensitivities

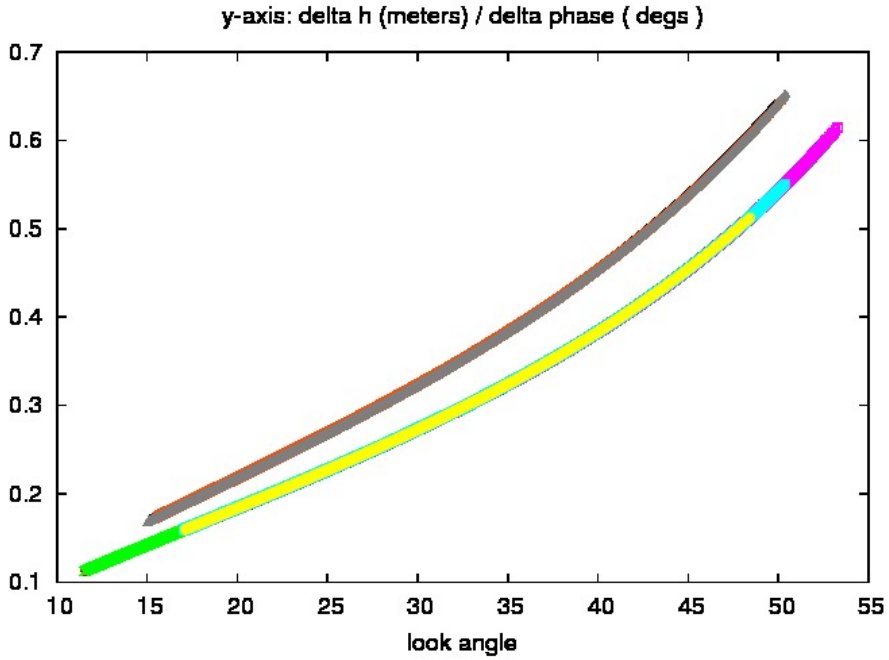
Small Wavelength (8.4 mm), Large Lever Arm, Ping-Pong Mode

Consequence #1: Ambiguous Heights

Platform Height	Near Range	Far Range
35K ft	38 meters	251 meters
41K ft	48 meters	267 meters

Consequence #2: Sensitivity to Roll and Phase Errors

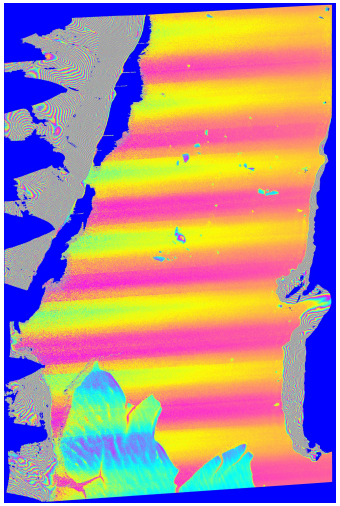




Removing Ripples Over Sea Ice 2016

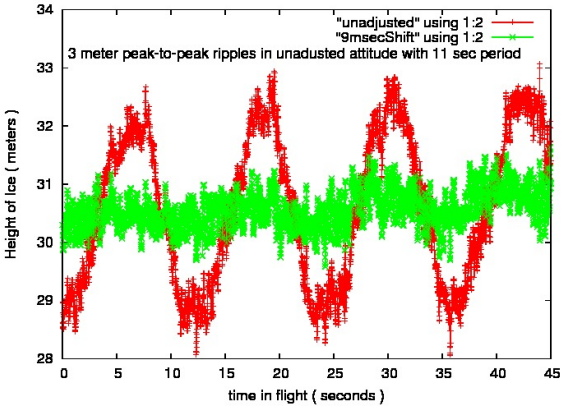
Greenl 00806 (79North, Western Greenland)

Unadjusted Attitude

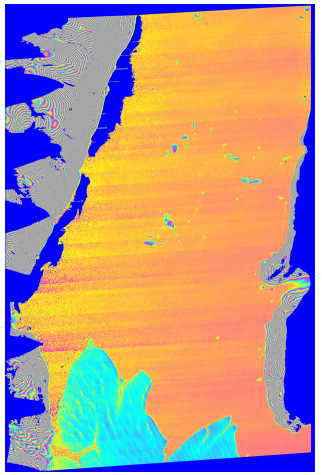


wrapped 20 m

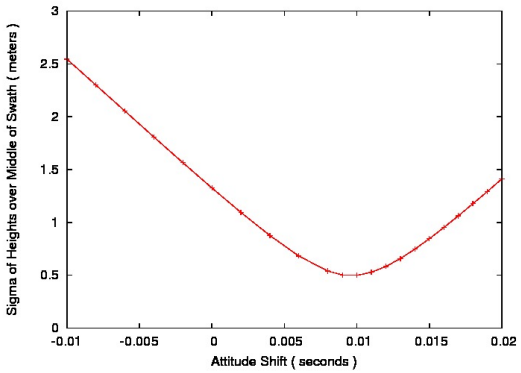
INU #1



9 millisec Shifted Attitude



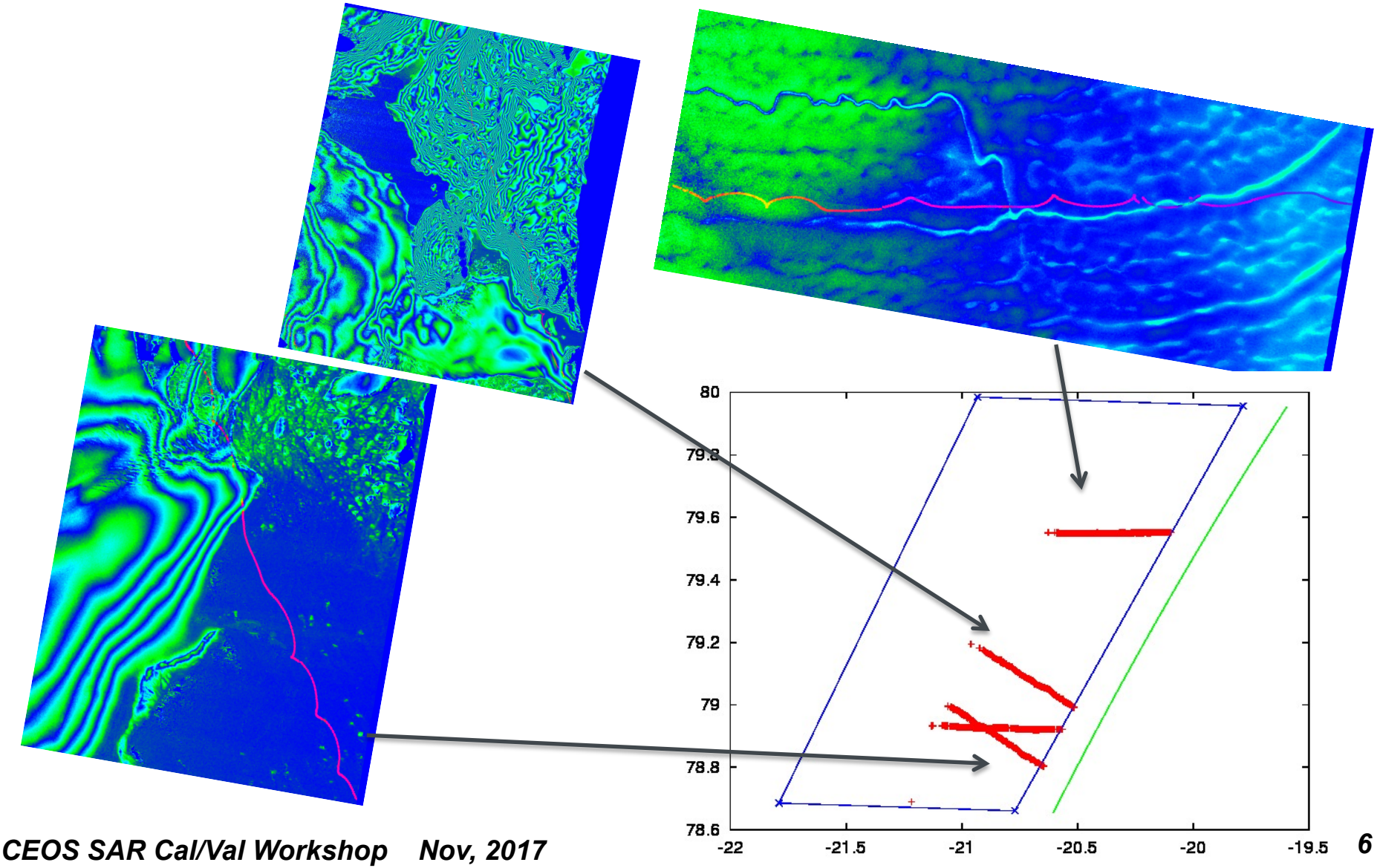
wrapped 20 m



<u>9 millisecs minimized sigma</u>
of heights over the flat regions
of the swath

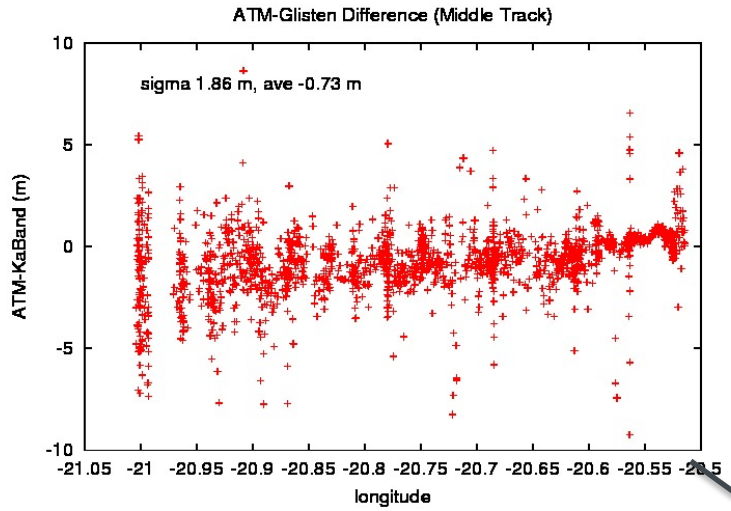
Comparison to ATM

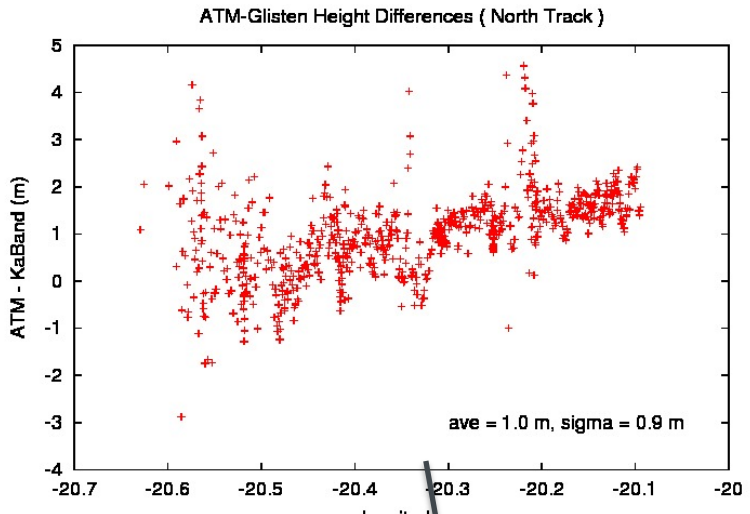
Ka-Band data March 31, 2016; ATM tracks May 9, 2016

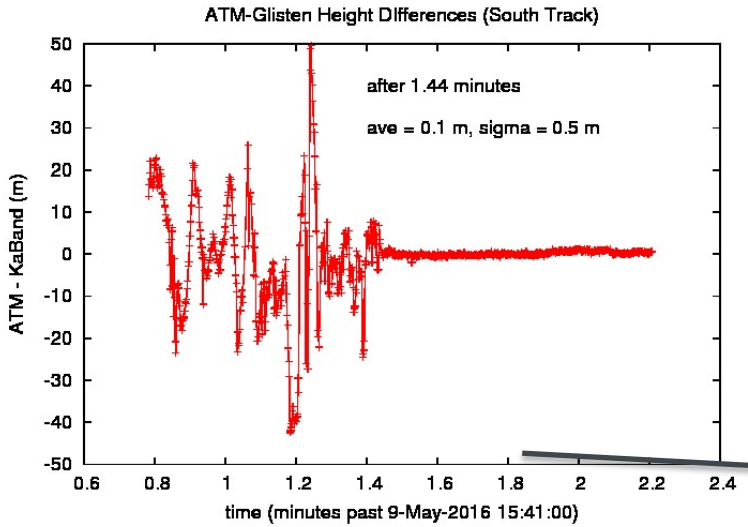


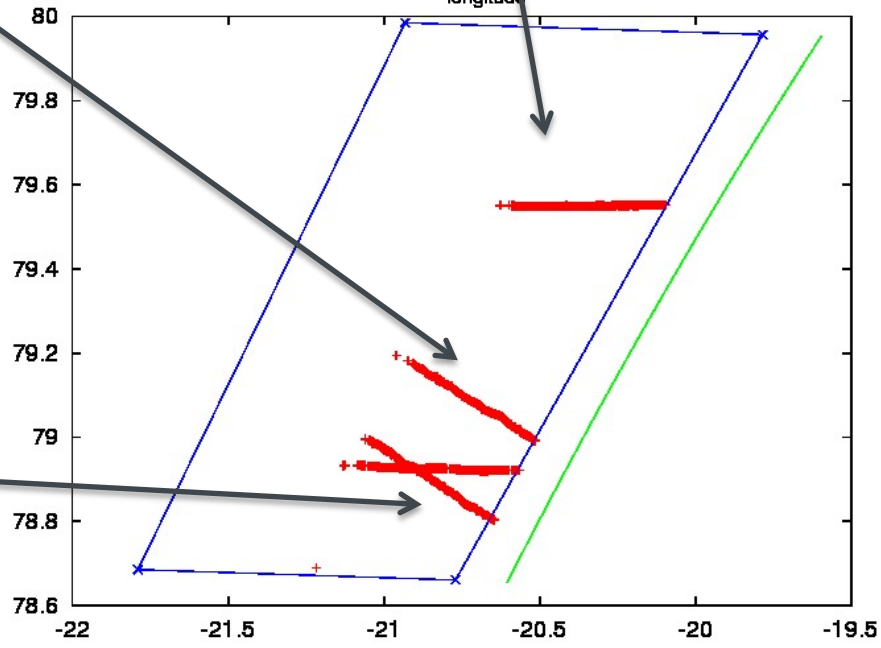
Comparison to ATM

Ka-Band data March 31, 2016; ATM tracks May 9, 2016







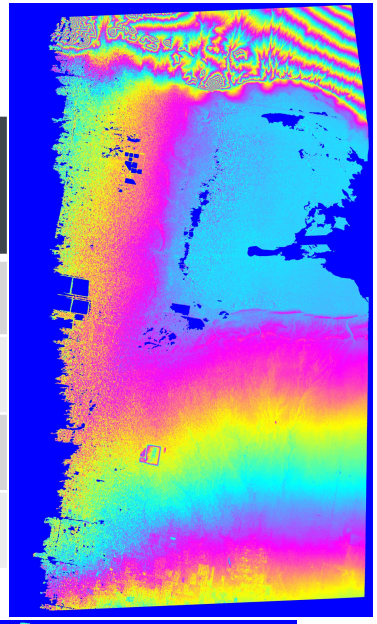


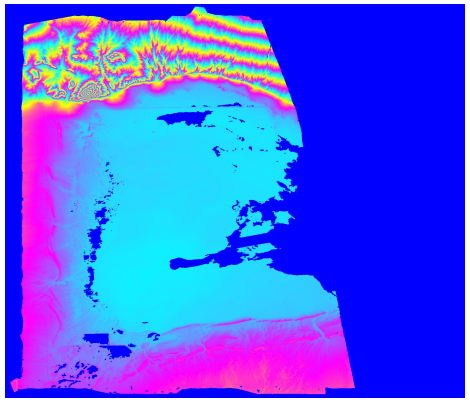
Rosamond Difference from ASO DEM

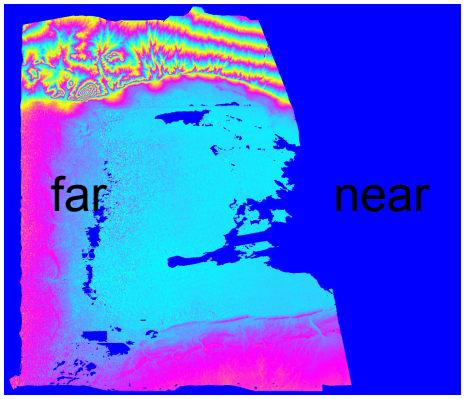
35K ft flight March 28, 2017

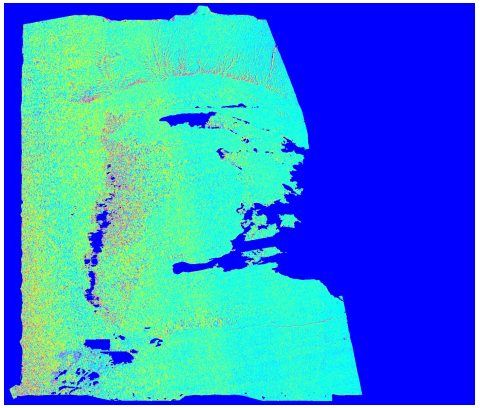
3 meter postings (12 to 48 look angle)

	Mean (m)	Sigma (m) < 1 meter err	Sigma (m) < 10 meter err
3503A _000	-0.84	0.58	0.71
1701H _001	0.33	0.55	1.08
3502X_003	-0.80	0.53	1.31
1701H_003	0.28	0.55	1.09









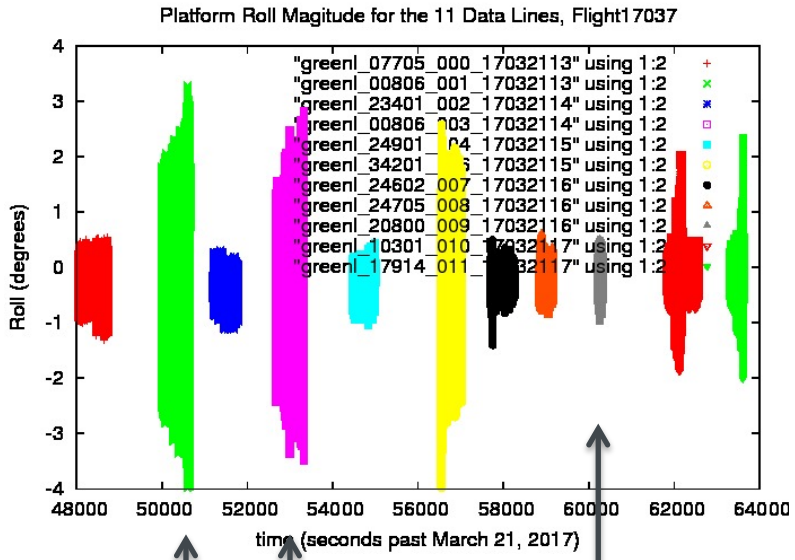
ASO wrapped 20 m

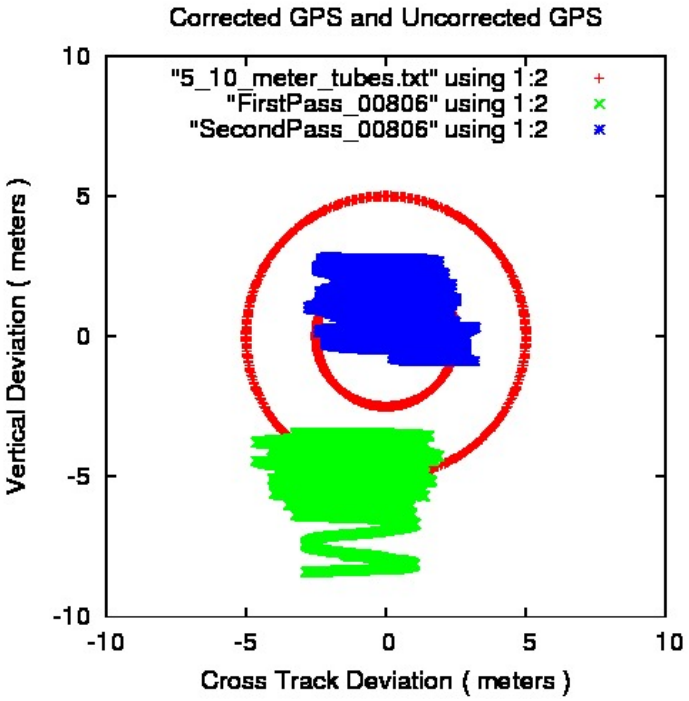
Ka-Band wrapped 20 m

Difference wrapped 5 m

Repeat Pass GreenI 00806, Now 2017

GreenI 00806 was repeated due to excessive roll and uncorrected GPS positioning. Second pass did not resolve the excessive roll however.





First Pass

Second Pass

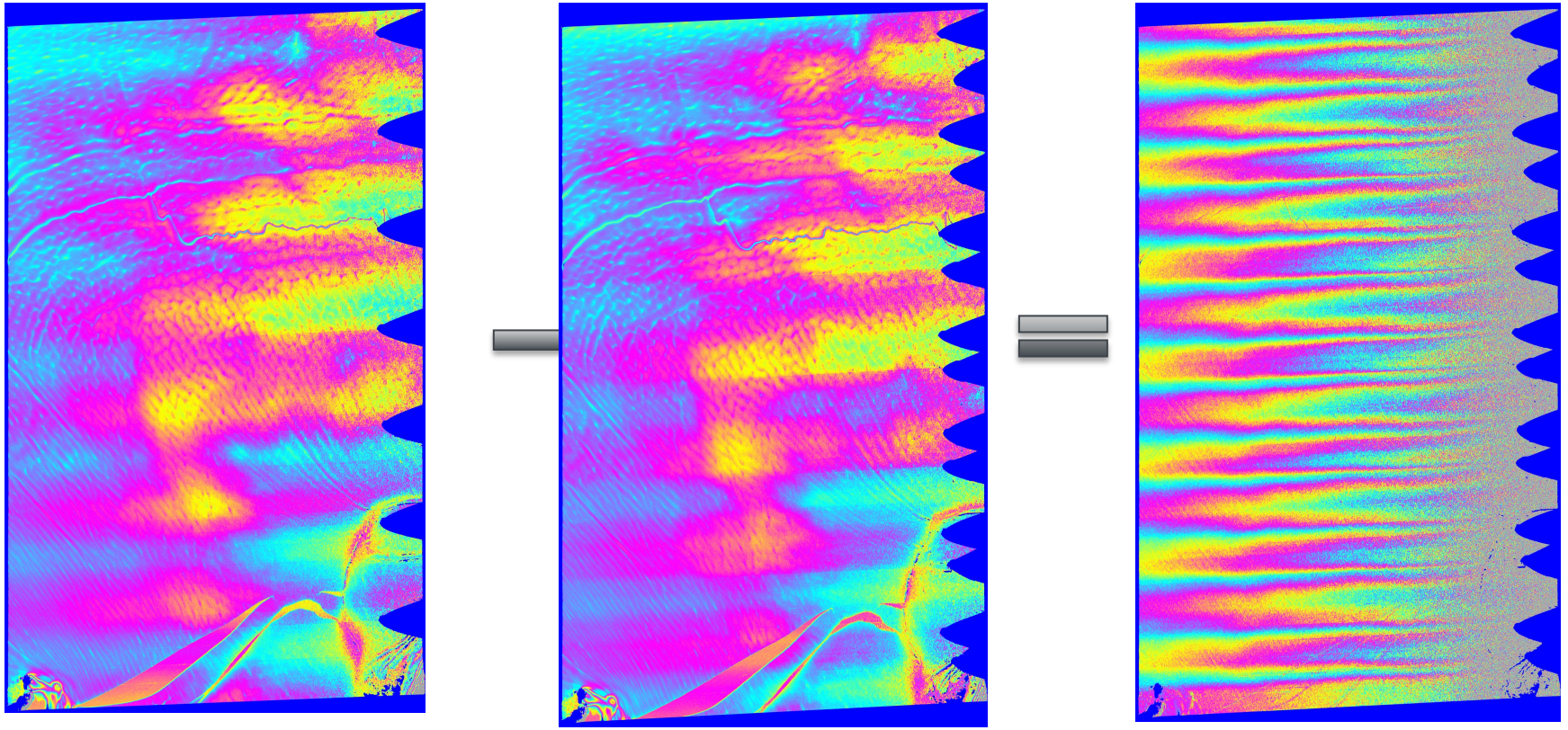
Engineering Sea Ice Line

6 meters difference in Vertical Deviation between the two passes.

Repeat Pass GreenI 00806, Now 2017

GreenI 00806 was repeated due to excessive roll and uncorrected GPS positioning. Second pass did not resolve the excessive roll however.

INU #2 Unadjusted attitude

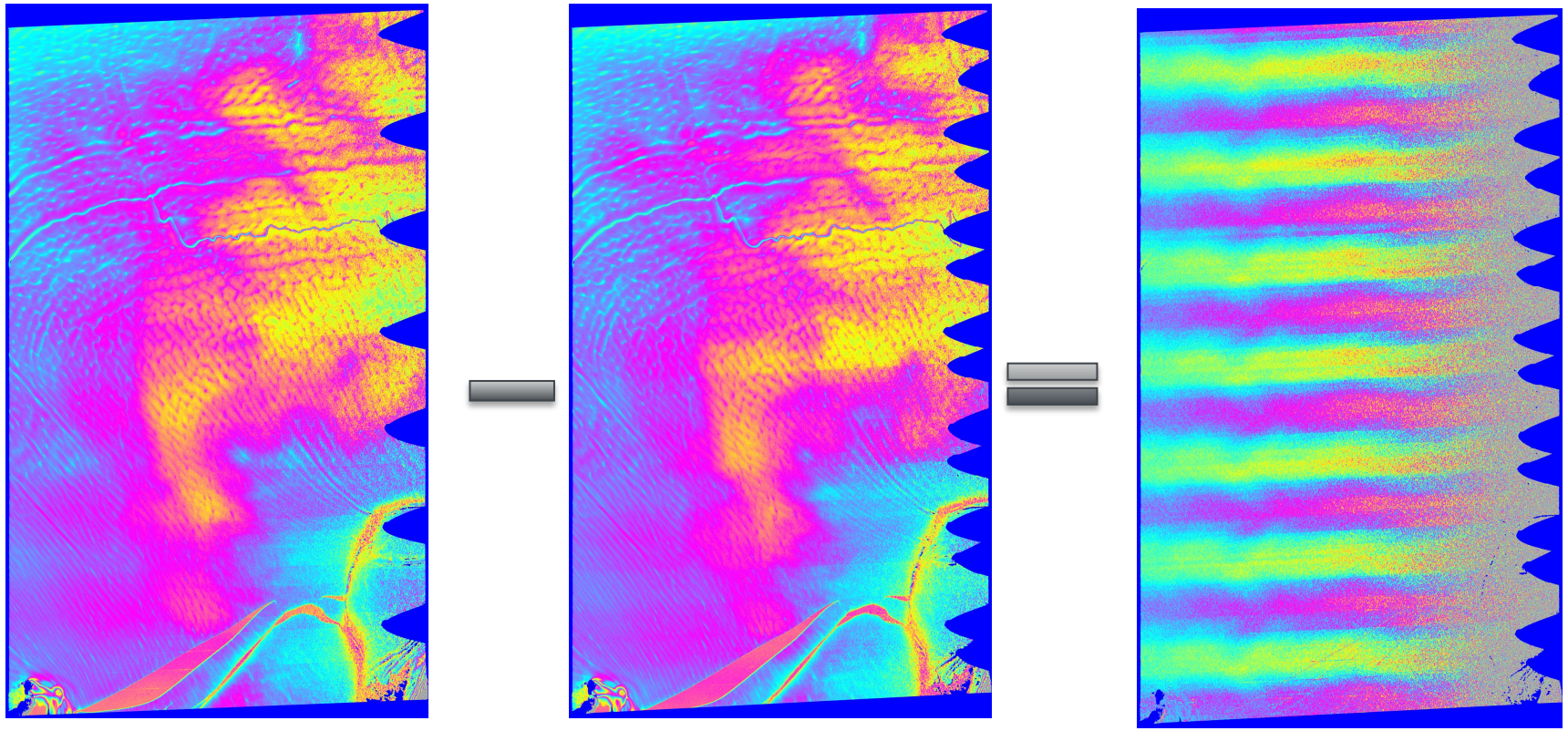


First Pass wrapped 20 m Second Pass wrapped 20 m Difference wrapped 5 m
0.34 m mean difference
3.82 m sigma

Repeat Pass GreenI 00806, Now 2017

GreenI 00806 was repeated due to excessive roll and uncorrected GPS positioning. Second pass did not resolve the excessive roll however.

INU #2 9 millisec shift in attitude

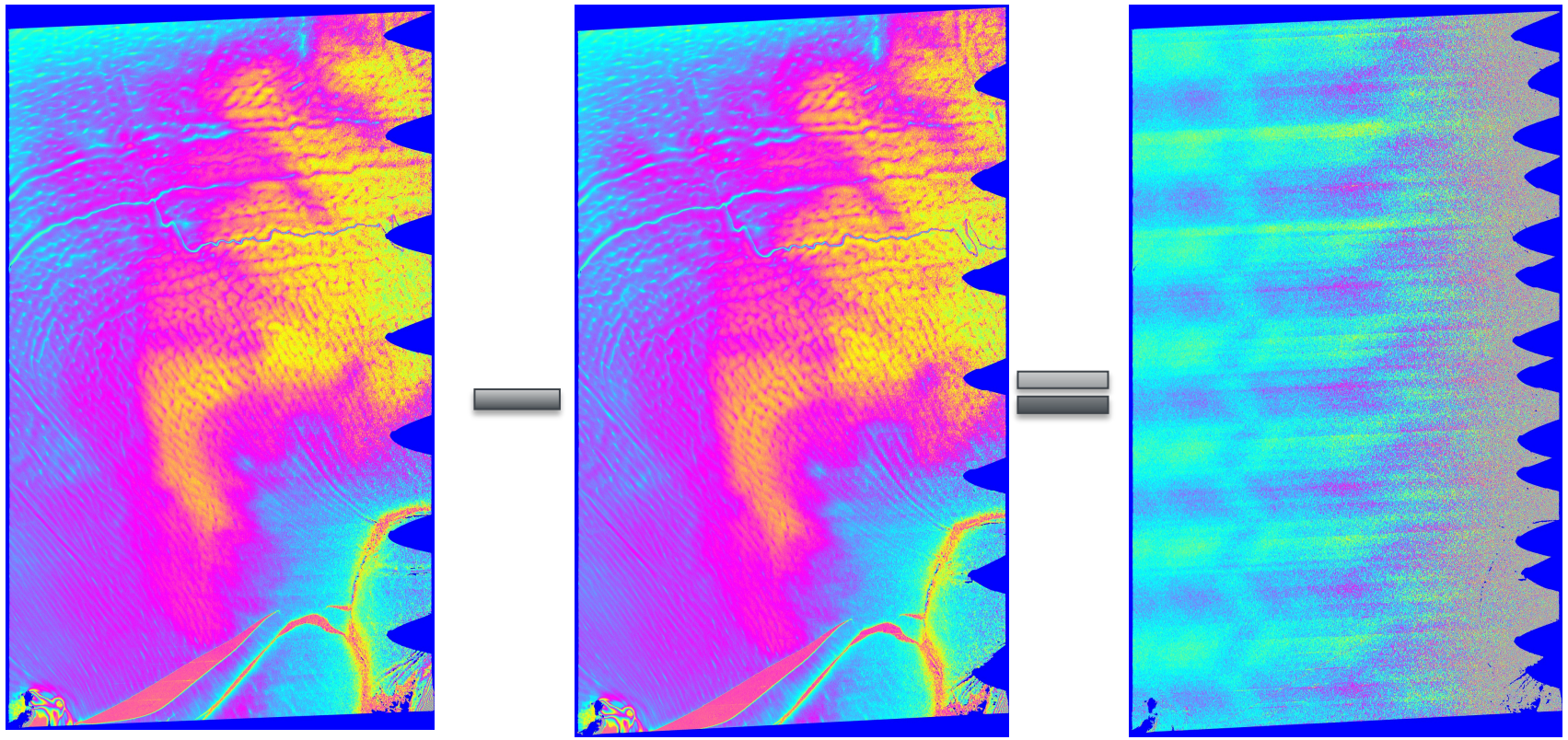


First Pass wrapped 20 m Second Pass wrapped 20 m Difference wrapped 5 m
0.28 m mean difference
1.71 m sigma

Repeat Pass GreenI 00806, 2017

GreenI 00806 was repeated due to excessive roll and uncorrected GPS positioning. Second pass did not resolve the excessive roll however.

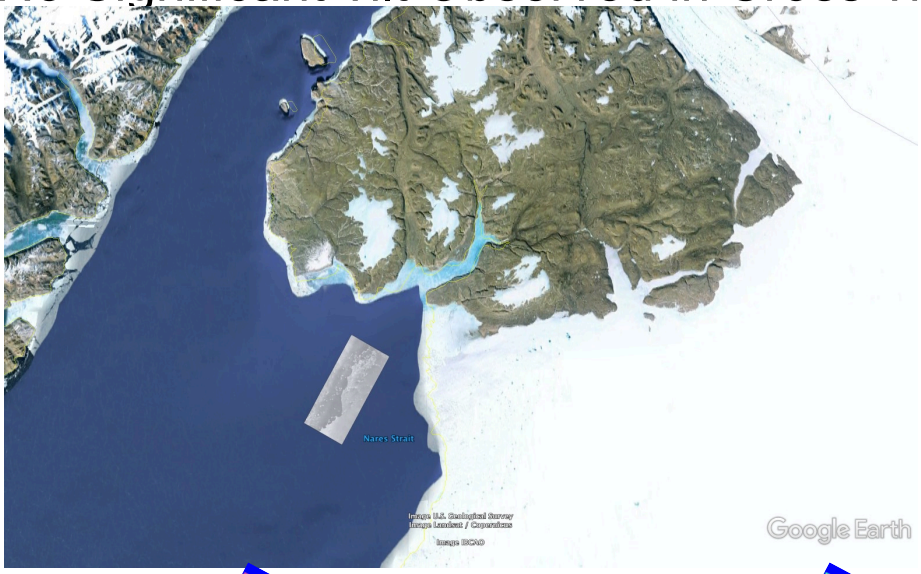
INU #2 14 millisec shift in attitude

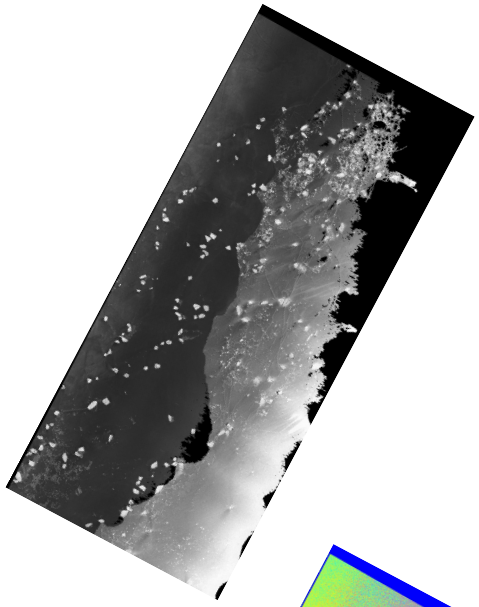


First Pass wrapped 20 m Second Pass wrapped 20 m Difference wrapped 5 m
0.19 m mean difference
0.64 m sigma

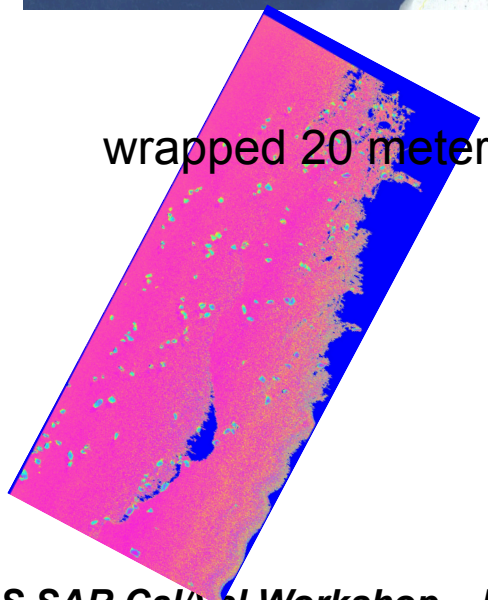
Engineering Sea Ice Line 20800, 2017

No Significant Tilt Observed in Cross Track

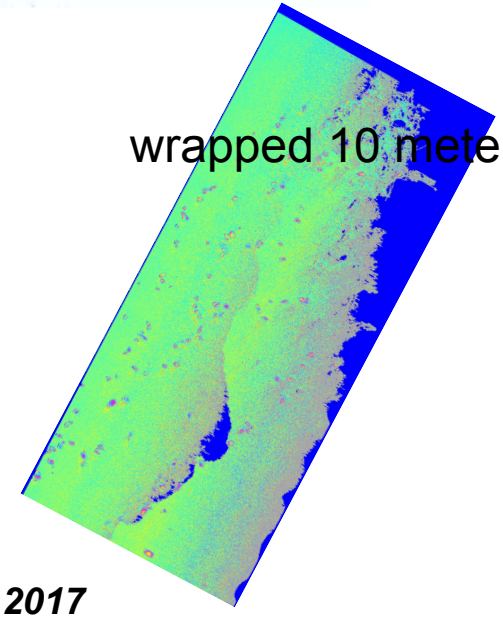




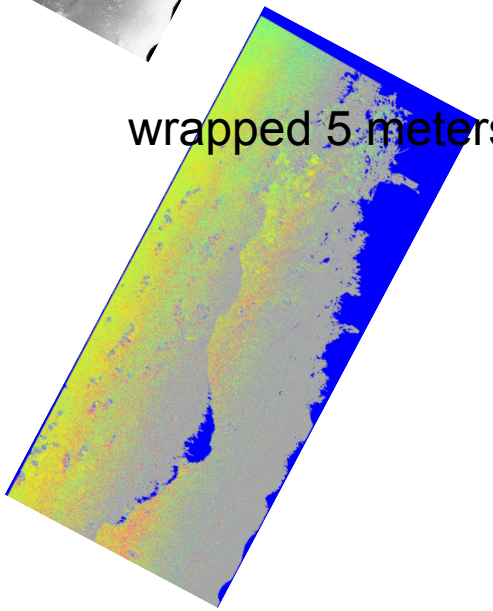
wrapped 20 meters



wrapped 10 meters

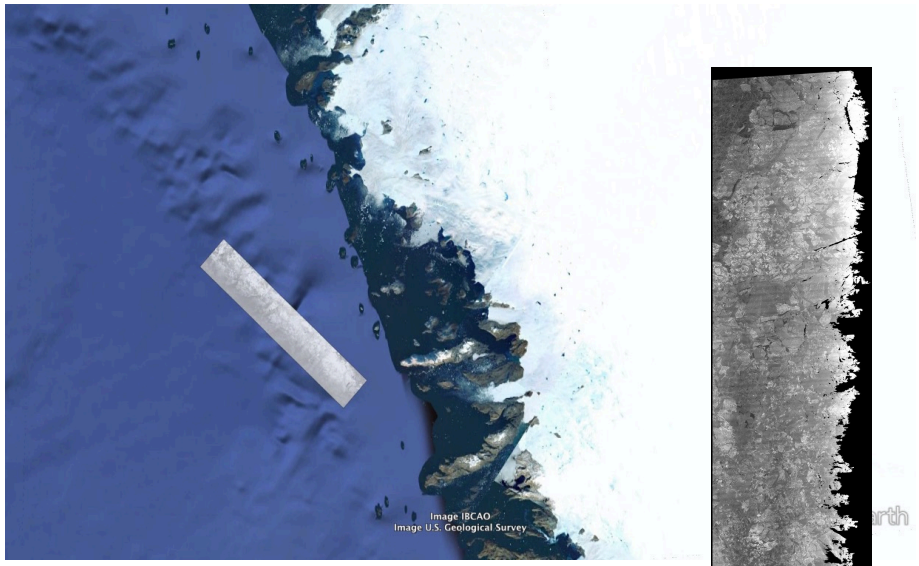


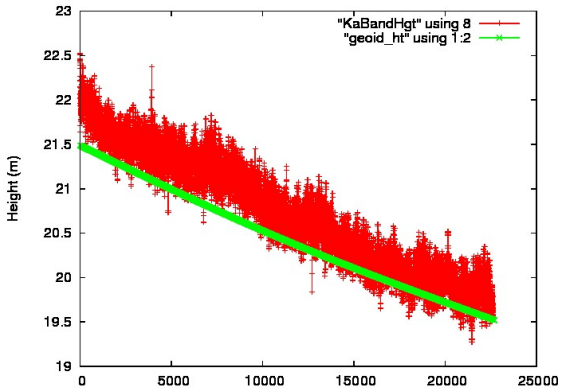
wrapped 5 meters

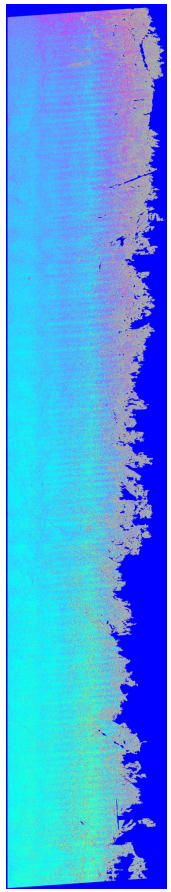


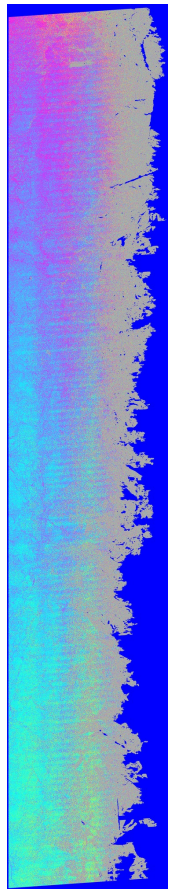
Engineering Sea Ice Line 31506. 2017

No Significant Tilt Observed in Cross Track, Along Track Follows Geoid









wrapped 10 meters wrapped 5 meters

Repeat Site Analysis, Comparing to SRTM

Repeated passes yielded non-trivial biases, Snowex 2017, Hawaii 2017

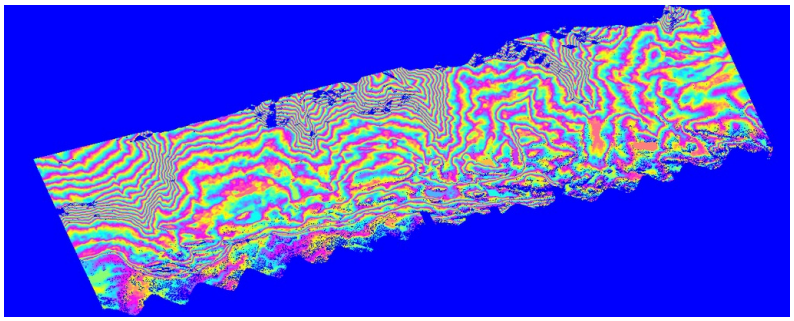
Flight 17013	Ave Diff (meters)	Sigma (meters)
grmesa_25206_008	9.09	4.59
snowex_07812_009	5.81	4.44
tellur_15318_000	7.65	6.40

Flight 17015	Ave Diff (meters)	Sigma (meters)
grmesa_25206_008	7.1	4.84
snowex_07812_009	4.20	4.42
tellur_15318_000	7.70	13.19

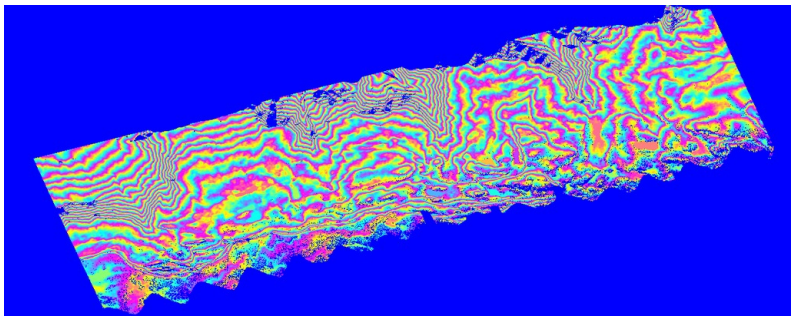
Flight 17015	Ave Diff (meters)	Sigma (meters)
grmesa_25206_008	7.1	4.84
snowex_07812_009	4.20	4.42
tellur_15318_000	7.70	13.19

Repeat Site Analysis

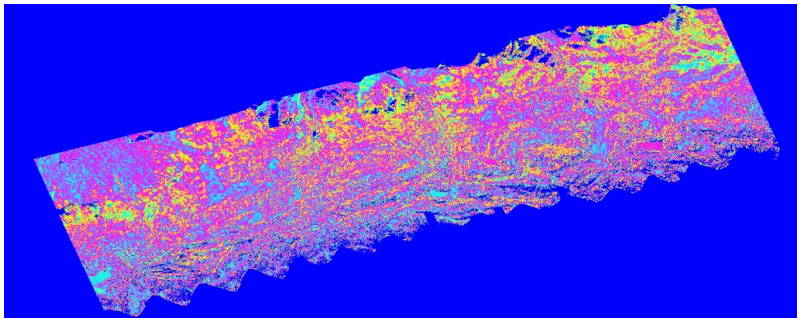
Difficult to assess DEM trends by absolute comparison with SRTM due to high slopes



Ka-Band DEM

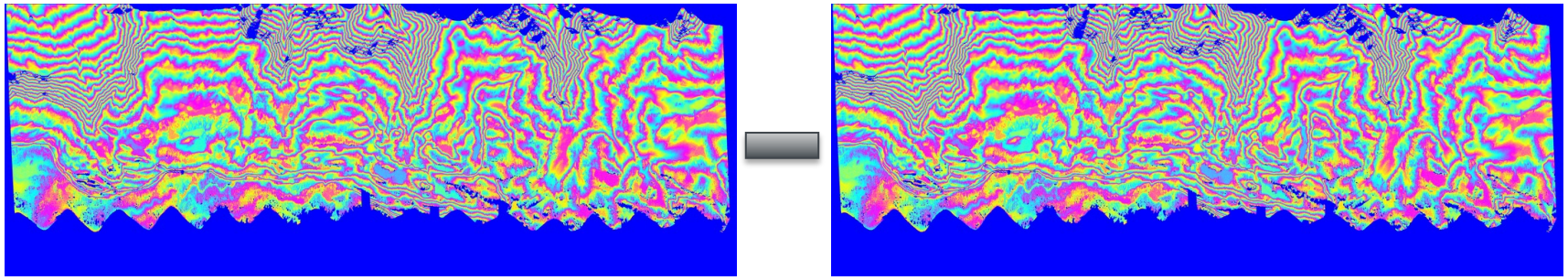


SRTM DEM



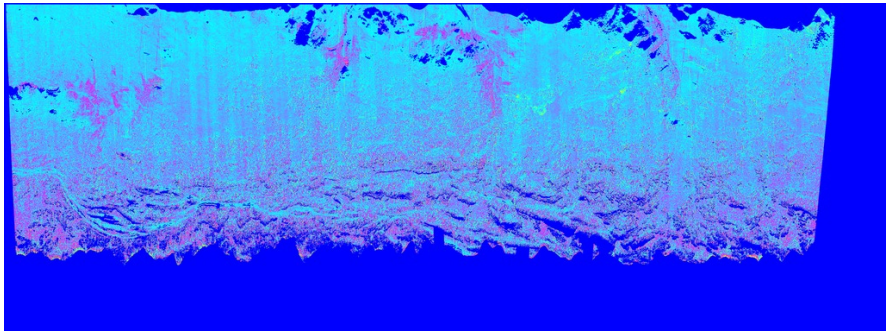
Repeat Site Analysis

Easier to assess DEM trends by relative comparison with repeated sites



First Pass

Second Pass



Use relative and not absolute heights

Look for closure of the estimates

(passA-passB) – (passA-passC) = (passC-passB)

Repeat Site Analysis

Relative Comparison Shows Closure

Flight 17015	Flight 17013	Ave Diff (meters)
grmesa_25206_008	grmesa_25206_008	2.03 (closure gives 2.05)
snowex_07812_009	snowex_07812_009	1.61 (closure gives 1.64)
tellur_15318_000	tellur_15318_000	0.06 (closure gives 0.07)

Flight 17017	Flight 17015	Ave Diff (meters)
grmesa_25206_001	grmesa_25206_008	-2.27
snowex_07812_000	snowex_07812_009	-1.40
tellur_15318_009	tellur_15318_000	-0.03

Flight 17017	Flight 17013	Ave Diff (meters)
grmesa_25206_001	grmesa_25206_008	-0.22
snowex_07812_000	snowex_07812_009	0.24
tellur_15318_009	tellur_15318_000	0.04

Repeat Site Analysis

Estimate Relative Roll Bias And Phase Bias to Align Differences

Flight 17015	Flight 17013	Roll (millideg)	Phase (degrees)
grmesa_25206_008	grmesa_25206_008	12.48 (close 12.11)	4.73 (closure 4.58)
snowex_07812_009	snowex_07812_009	10.58 (close 10.15)	4.00 (closure 3.81)
tellur_15318_000	tellur_15318_000	-0.87 (close -0.70)	-0.32 (closure -0.25)

Flight 17017	Flight 17015	Roll (millideg)	Phase (degrees)
grmesa_25206_001	grmesa_25206_008	-14.53	-5.50
snowex_07812_000	snowex_07812_009	-10.17	-3.87
tellur_15318_009	tellur_15318_000	0.29	0.11

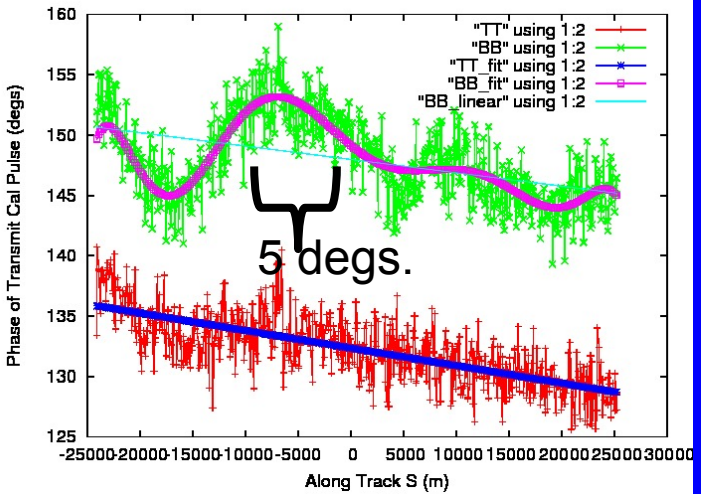
Flight 17017	Flight 17013	Roll (millideg)	Phase (degrees)
grmesa_25206_001	grmesa_25206_008	-2.42	-0.92
snowex_07812_000	snowex_07812_009	-0.16	-0.06
tellur_15318_009	tellur_15318_000	-0.41	-0.14

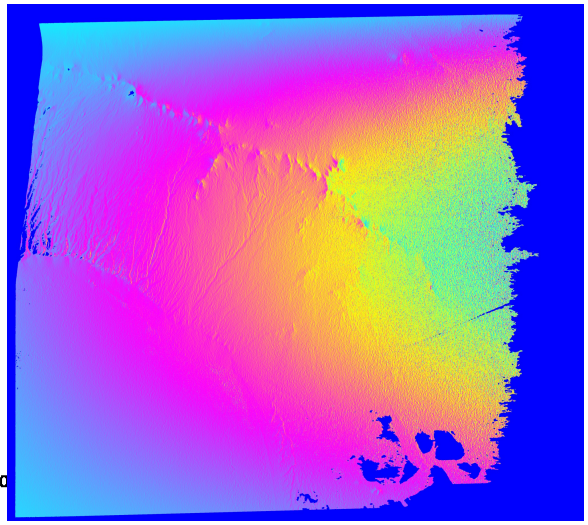
All wrapped 3 meters

Systematic Phase Drifts

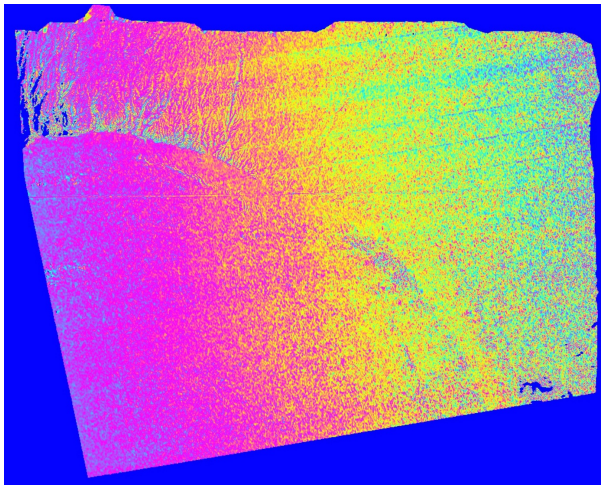
Internal Transmitter Cal Pulse Models Phase Drifts

Anomalous Rosamond Engineering Calibration Line April 7, 2016

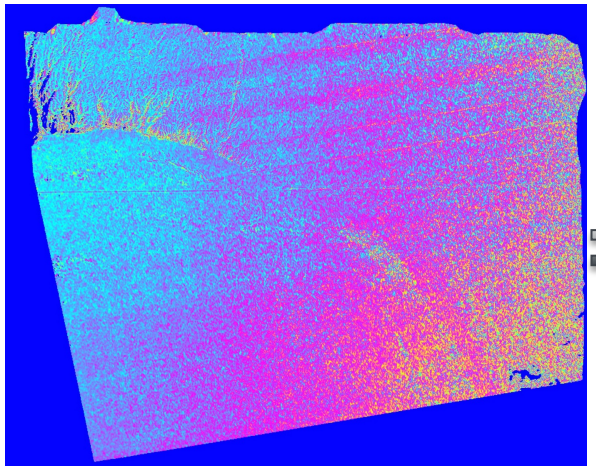




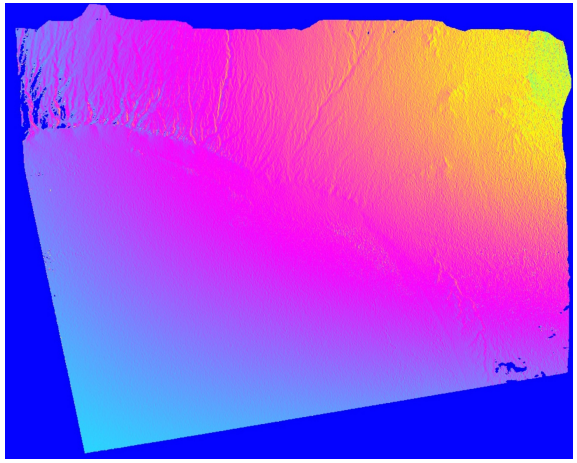
LinearBB - HighOrderBB



ASO-KaBand(LinearBB)



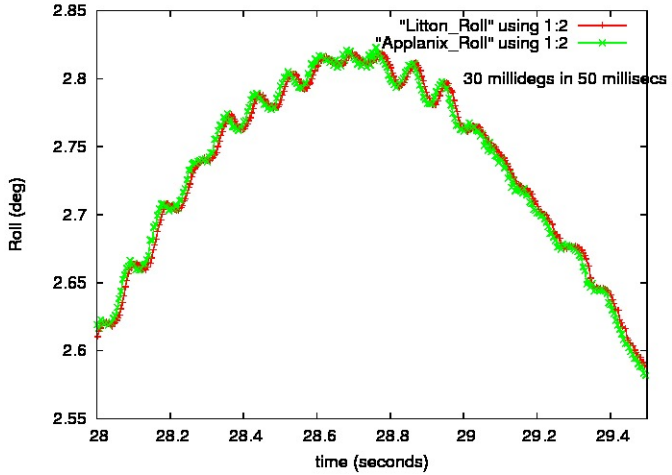
ASO-KaBand(HighOrderBB)

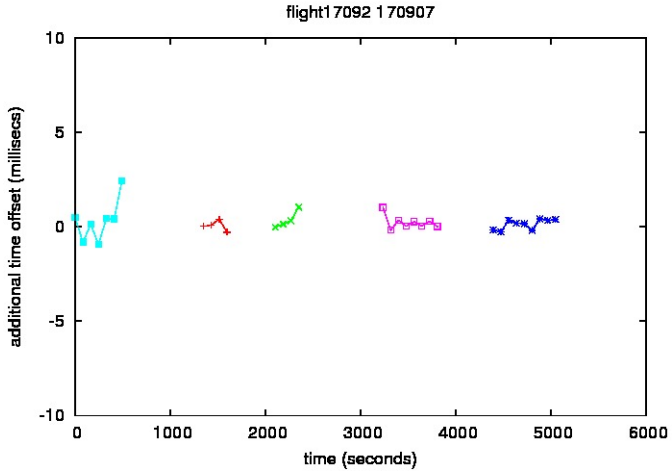


LinearBB - HighOrderBB

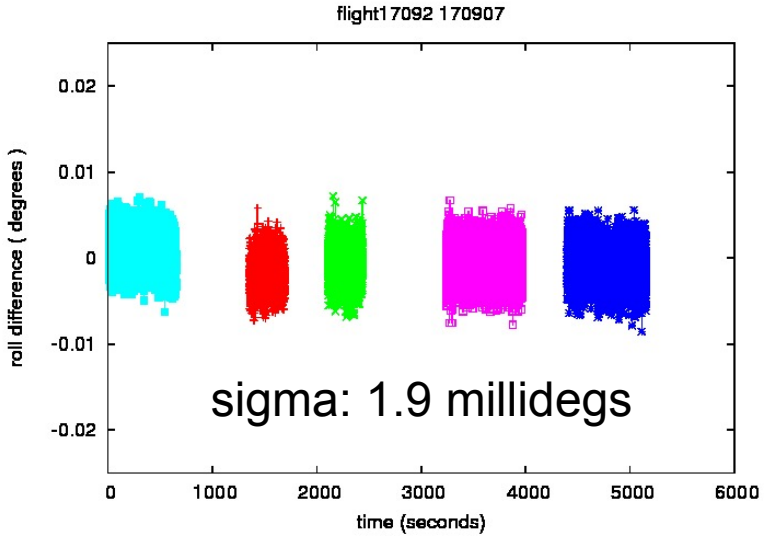
Difference of Applanix IMU Attitude with IMU #3

IMU #3 was refurbished in 2017





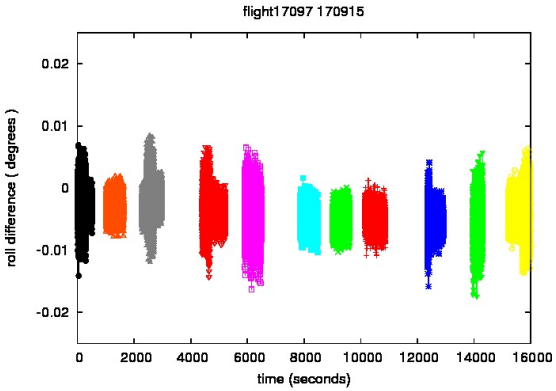
With nominal 11 millisecond offset



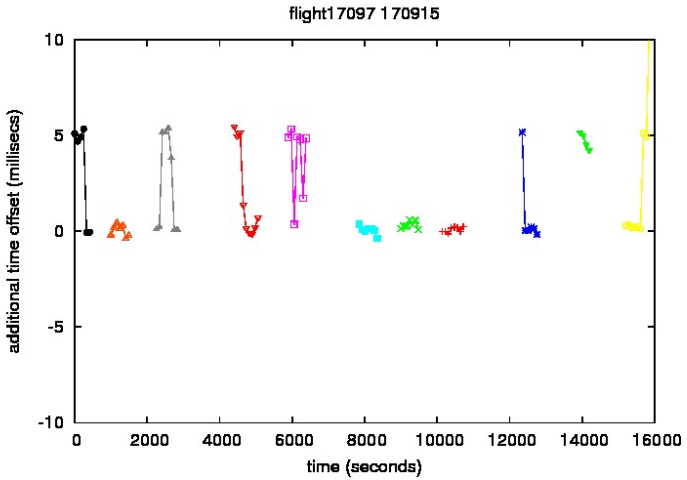
Average Difference: -0.0005 degrees
PosPac Angles 0.481,19.042,-89.365

Seven Consecutive Flights with Applanix

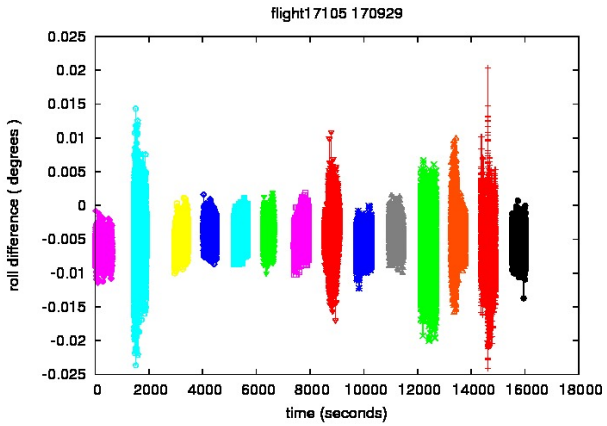
IMU #3 Comparison



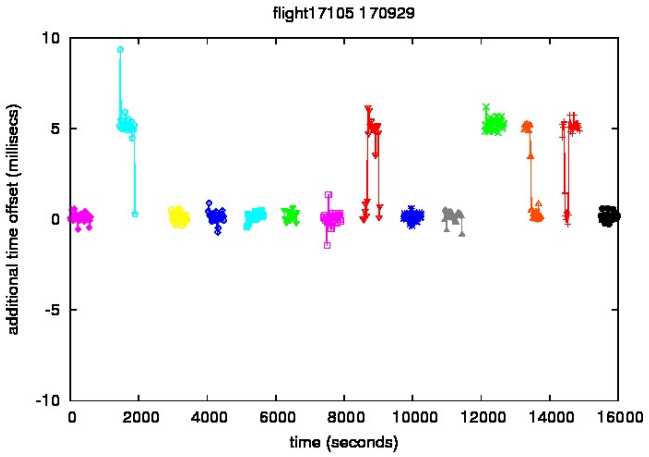
Average Difference: -0.004 degrees
5 lines have > -0.005 degrees average



With nominal 11 millisecond offset



Average Difference: -0.005 degrees
First Line Average Diff: -0.006 degrees



Evidence for Roll Bias in IMU

~10 millideg bias in the IMU # 2 caused up to 2 meter relative bias between Ka-Band DEM

- 2016 IMU #1 attitude shift 0.009 seconds
- 2017 IMU #2 attitude shift 0.014 seconds
- Refurbished IMU #3 attitude shift 0.011 seconds
  - Observed up to 6 millidegree biases in Roll compared to Applanix
  - Transmit calibration pulses are tracking systematic phase drifts

<u>Fly IMU #3 with Applanix in 2018 Ka-band Missions to account for Roll Bias of IMU.</u>

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov